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(21) International Application Number: PCT/US96/18363 (22) International Filing Date: 15 November 1996 (15.11.96) (30) Priority Data: 08/558,847 15 November 1995 (15.11.95) US (71)(72) Applicants and Inventors: SOROUSHIAN, Parviz [US/US]; DPD, Inc., 2000 Turner Street, Lansing, MI 48906 (US). HSU, Jer-Wen [CN/US]; 2000 Turner Street, Lansing, MI 48906 (US). (74) Common Representative: SOROUSHIAN, Parviz; DPD, Inc., 2000 Turner Street, Lansing, MI 48906 (US).		(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>
(54) Title: DISPERSION OF PLANT PULP IN CONCRETE AND USE THEREOF (57) Abstract The wet pulp derived from wood, plants or waste paper is dried to a relatively low density with limited bonding developed between fibers. The resulting dried pulp is conveniently broken up, using limited mechanical energy and without substantially damaging the fibers, into individual fibers for use as reinforcement in cement-based materials.		

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1 **Dispersion of Plant Pulp in Concrete and Use Thereof**

2

3

4 **Cross-References to Related Applications**

5 None.

6 **Statement as to Rights to Inventions Made Under Federally-Sponsored Research**
7 **and Development**

8 None.

9 **Background of the Invention**

10 *Field of the Invention*

11 The invention relates to plant and wood pulp fibers and cement-based materials,
12 and especially to the processing of plant and wood pulp fibers for the reinforcement of
13 cement-based materials.

14 *Description of the Prior Art*

15 Pulp fibers derived by mechanical, thermo-mechanical and chemical methods, or
16 combinations thereof, from different wood species and plants offer excellent
17 characteristics for the reinforcement of cement-based materials. These characteristics
18 include:

19 (1) Wood and plant pulp fibers provide equivalent cross-sectional diameters of about 1-
20 100 microns, and lengths of about 0.2-10 mm. Equivalent diameter here refers to the
21 diameter of a circle which provides the same cross-sectional area as the fiber. The fine
22 diameter of such fibers increases their surface area and the number of fibers per unit
23 weight. For example, 1 kg of southern pine kraft pulp fibers provides close to 1.8

1 billion fibers with total surface area of approximately 250 million mm²; plant and wood
2 pulp fibers thus provide a close fiber spacing and a high fiber surface area per unit
3 weight addition to cement-based materials. These characteristics benefit the action of
4 plant and wood pulp fibers as reinforcement in cement-based matrices. Furthermore,
5 the relatively high length-to-equivalent diameter ratio of plant and wood pulp fibers
6 provides for desirable anchorage of fibers within cement-based matrices and helps fully
7 mobilize the tensile strength of fibers in the composite system. The equivalent
8 diameter of many plant and pulp fibers is within the range of the particle size of
9 Portland cement; this favors compact packing of the cement particles around fibers,
10 and favors improvements in the hardened material micro-structure and properties.

11 (2) Plant and wood pulp fibers generally provide high levels of tensile strength and elastic
12 modulus, which benefit their effectiveness as reinforcement in cement-based matrices.

13 (3) Plant and wood pulp fibers provide hydrophilic surfaces which also develop strong
14 bonding to cement-based matrices. Hydrophilic fiber surfaces facilitate uniform
15 dispersion of fibers in the aqueous environment of fresh cement-based matrices. The
16 strong bonding of these surfaces to the cement-based matrix also favors the
17 effectiveness of plant and wood pulp fibers as discrete reinforcement in cement-based
18 materials.

19 (4) Many plant and wood pulp fibers, especially kraft wood pulp, are stable in alkaline
20 environments. The environment in many cement-based matrices is alkline and thus the
21 alkali resistance of fibers favors improved long-term durability of fiber reinforced
22 composite systems.

1 The pulping process for deriving fibers from wood and plant, or from waste paper
2 incorporating such fibers, is a wet process and yields fibers with a moisture content in
3 excess of about 90% by weight. If the pulp is to be marketed for the production of paper
4 products, its moisture content is reduced through pressing and heating. Since pressing
5 presents a more efficient approach to moisture removal, pulp mills rely heavily on
6 pressing, in lieu of heating, to dry the wet pulp into compacted sheets of pulp with a high
7 density of about 0.85-1.2 g/cm³ at a moisture content of less than about 10% by weight.
8 Heavy use of pressing in the drying process leads to the development of strong hydrogen
9 bonds between a substantial fraction of the surfaces of adjacent fibers. Any subsequent
10 use of the pulp as individual fibers involves breaking of the hydrogen bonds between fibers
11 to separate them from each other. This process of separating pulp fibers from each other
12 should not damage or cut the fibers. Noting that moisture helps break the hydrogen
13 bonds, wetting of the pulp to moisture contents exceeding about 90% by weight is used in
14 paper production to facilitate the separation of individual fibers by mechanical action.

15 The processing of plant and wood pulp fibers into fiber reinforced cement
16 composites has traditionally involved the use of the available paper pulp which has been
17 dried by heavy reliance on pressing accompanied with heating into a dense pulp with
18 strong fiber-to-fiber bonding. The common method for separating individual fibers from
19 such highly pressed pulp sheets involves the use of moisture together with mechanical
20 action to break the fiber bonds and make individual fibers available for uniform dispersion
21 in cement-based matrices. Subsequently, when excess water is used in the fiber separation
22 and dispersion process, a fraction of the water may be removed from the wet composite
23 system using vacuum and mechanical pressure. This process has been used, for example,

1 in U.S. Patent No. 4,985,119 to Vinson et al. (1991) and U.S. Patent No. 5,102,596 to
2 Lempfer et al. (1992). The strong fiber-to-fiber bonding in such pulp sheets, which have
3 been dried through heavy pressing for use in paper production, increases the need for
4 moisture and mechanical action to break up the pulp into individual fibers for use as
5 reinforcement in cement-based matrices. The resistance provided by the strong fiber-to-
6 fiber bonds increases the damage to fibers in the process, which is a detriment to the
7 reinforcement efficiency of fibers. This strong bond also renders the mechanical
8 separation action less effective and thus leaves agglomerates of multiple unseparated
9 fibers.

10 The use of mechanical action without added moisture is also an option for
11 separating the fibers from the highly pressed pulp sheets, or even from paper products
12 where strong hydrogen bonding between fibers provides for the integrity of paper. Dry
13 separation of pulp fibers has been referred to in U.S. Patent No. 3,753,749 to Nutt (1973).
14 The dry process of separating bonded pulp fibers does not have the benefit of water to
15 break hydrogen bonds between fibers and thus relies on a more intense mechanical action
16 to break up the highly pressed pulp sheets into individual fibers for use as discrete
17 reinforcement in cement-based matrices. Such mechanical action may be applied to the
18 pulp sheets using a mill such as hammer mill, pin mill, or the like. The intense mechanical
19 action required to break up the highly pressed pulp sheets causes increased damage to
20 fibers and leaves many broken fibers and fines with reduced reinforcement efficiency.
21 Also, given the strong hydrogen bonding between fiber surfaces in a highly pressed pulp
22 sheet, dry mechanical processing still leaves a fraction of the pulp mass as agglomerates or
23 knots comprising multiple fibers which are still bonded together. Such multiple fiber

1 agglomerates are not effective as reinforcement in cement-based matrices and could
2 actually damage the performance of such matrices.

3 It is, therefore, the principal object of the present invention to provide an improved
4 method of drying pulp which facilitates subsequent separation of the dried pulp into
5 individual fibers for use as discrete reinforcement in cement-based materials.

6 It is also an object of the invention to provide improved cellulose fiber reinforced
7 cement-based materials with desirable performance in fresh and hardened states.

8 **Summary of the Invention**

9 The principal object of the present invention is to dry wood and plant pulp fibers
10 so that fiber-to-fiber bonding is reduced, and thus the dried pulp can be effectively and
11 efficiently separated into individual fibers for addition to cement-based materials as
12 discrete reinforcement. The drying process differs from that used in paper pulp
13 production by avoiding heavy pressing of the pulp in the drying process, or the addition of
14 surfactant to the wet pulp prior to drying, or a combination thereof. The reduced fiber-to-
15 fiber bonding in such dried pulp facilitates subsequent processing of the pulp into
16 individual fibers using mechanical action with or without the use of water in the process.
17 The mechanical energy required to break up the dried pulp into individual fibers is thus
18 reduced, and the separation process causes less damage to fibers and leaves less multiple
19 fiber agglomerates. The resulting fibers are more effective as discrete reinforcement in
20 cement-based materials.

21 **Brief Description of the Drawings**

22 None.

1 Description of the Preferred Embodiments

2 The addition of slender fibers to cement-based materials improves the
3 cohesiveness, finishability, pumpability, segregation resistance and cracking resistance of
4 such mixtures in the fresh state, and also enhances their toughness, impact resistance,
5 strength, cracking resistance and durability in the hardened state. To be effective,
6 individual fibers should be uniformly dispersed in cement-based materials. Most fibers,
7 including steel and nylon fibers, are produced as individual fibers which do not have a
8 tendency for fiber-to-fiber bonding. The resulting fibers can thus be added to fresh
9 cement-based mixtures as individual fibers to be dispersed in the mix through the
10 mechanical mixing action. Cellulose fibers are derived from different softwood and
11 hardwood species, plants such as flax and cotton, or waste paper in a wet process which
12 may involve thermal, mechanical and chemical effects or combinations thereof. The
13 resulting wet pulp fibers contain more than 90% by weight moisture content, and should
14 be dried to a moisture content less than 10% by weight prior to shipment. The common
15 drying process relies heavily on pressing which is more efficient than heating for the drying
16 of pulp; this process produces strong hydrogen bonds between fibers and produces pulp
17 sheets with a relatively high density of $0.85\text{-}1.2\text{ g/cm}^3$. These hydrogen bonds should be
18 subsequently broken in order to produce individual fibers needed for the reinforcement of
19 cement-based materials. The breaking of fiber-to-fiber bonds in dried pulp can be
20 accomplished using mechanical action with or without the addition of moisture to the
21 pulp. The use of moisture weakens fiber-to-fiber bonding and thus facilitates the
22 separation of fibers by mechanical action. When water is added to the previously dried
23 pulp, the moistened pulp with about 50-1000% moisture content is subjected to blending,

1 beating or milling actions, or the like, for breaking up the pulp and reducing it to
2 individual fibers. Without the addition of moisture, one may use the mechanical action of
3 a mill such as a pin mill, a hammer mill, or the like in order to overcome the fiber-to-fiber
4 bonds and separate individual fibers from the dried pulp. The strong hydrogen bonding
5 between cellulose fiber surfaces in the pulp which has been dried with heavy reliance on
6 pressing, as is the case in the pulp marketed to the paper industry, necessitates the use of
7 a more intense mechanical action for the separation of individual fibers from the pulp.
8 This not only increases the energy requirement in the process of deriving individual fibers
9 from the dried pulp, but also causes damage to fibers, breaks many fibers into short fibers
10 and fines, and leaves many multiple fiber agglomerates. The damaged and broken fibers as
11 well as multiple fiber agglomerates are not effective as discrete reinforcement in cement-
12 based materials. This is a detriment to the reinforcement efficiency of fibers separated
13 from the highly pressed pulp dried for marketing to the paper industry when such fibers
14 are used as reinforcement in cement-based materials. It is thus desirable to refine the
15 drying process that is commonly applied to paper pulp in order to reduce the extent of
16 fiber-to-fiber bonding in the dried pulp and thus enhance the effectiveness and efficiency of
17 the subsequent process of breaking up of the dried pulp into individual fibers for use as
18 discrete reinforcement in cement-based materials.

19 The invention described herein refines the drying process of wet pulp fibers to
20 achieve moisture contents below about 10% by weight through reducing the reliance on
21 pressing and increasing the reliance on heating in the drying process, addition of surfactant
22 to the wet pulp prior to drying, or a combination thereof. The result is a lighter-weight or
23 fluff pulp that is less dense when compared with paper pulp, with a density of about 0.2-

1 0.8 g/cm³; the fiber surfaces in such dried pulp develop less hydrogen bonding to each
2 other. The pulp can thus be broken up into individual fibers more effectively and
3 efficiently with or without the addition of water. Less mechanical energy is needed in
4 separating individual fibers from such dried pulp and the process causes less damage to
5 fibers and leaves less broken fibers, fines, or multiple fiber agglomerates. The resulting
6 individual fibers thus provide a higher reinforcement efficiency when dispersed in cement-
7 based matrices.

8 The dried pulp thus obtained by less reliance on pressing in the drying process,
9 addition of surfactant prior to or during drying, or a combination thereof, is then broken
10 up into individual fibers by mechanical action with or without the addition of water to the
11 pulp. When moisture is not added to the dried pulp, the mechanical action to separate
12 individual fibers from the dried pulp may be provided by a mill, such as hammer mill, pin
13 mill, or the like. When moisture is added, the wet pulp reaches moisture contents of about
14 50-1000% by weight, with the added moisture being part or all of the water needed in the
15 cement-based mix, or even exceeding that needed in the mix. The excess moisture, if any,
16 should be subsequently removed from the mix using vacuum, pressure, heat, or
17 combinations thereof. The separation process of such pulp dried to reduce fiber-to-fiber
18 bonding, with or without the addition of water, consumes less energy, causes less damage
19 to fibers, and leaves less broken fibers, fines, or multiple fiber agglomerates. The result is
20 individualized fibers which can be conveniently dispersed in cement-based mixtures and
21 offer high levels of reinforcement efficiency. The fibers separated from such pulp
22 may be added to cement-based mixtures at about 0.01-40% volume fraction, and
23 preferably at about 0.05-5% volume fraction which corresponds to approximately 0.7-45

1 kg/m³. Such cement-based mixtures may be concrete comprising cement, fine aggregate,
2 coarse aggregate and different admixtures. Fine and coarse aggregates could be of
3 mineral, synthetic, metallic or organic sources with fine aggregate-to-cement weight ratios
4 of about 0.1-30 and coarse aggregate-to-cement weight ratios of about 0.1-30. The
5 maximum particle size in fine and coarse aggregates is less than about 6 mm and less than
6 about 75 mm in size, respectively. The cement binder in concrete may be hydraulic
7 cement such as different types of Portland cement, blended cement, expansive cement,
8 high-alumina cement, masonry cement, block cement, magnesium phosphate cement, or
9 set-regulated cement. The water-cement ratio in concrete is about 0.1-0.9 by weight.
10 Various admixtures may also be used in concrete including air-entraining admixtures, set-
11 accelerating admixtures, set-retarding admixtures, polymeric admixtures, pozzolanic
12 admixtures, water-reducers, superplasticizers, or combinations thereof. The cement-based
13 mixtures into which the cellulose fibers are dispersed may also be mortar which is
14 essentially the same as concrete but without the coarse aggregate. The maximum particle
15 size of fine aggregates in mortar could be less than 5 mm, and as small as 0.05 mm. The
16 cement binder in mortar could be any of the hydraulic cements used in concrete; this
17 binder could also be of hydratable type such as gypsum or plaster. The water-cement
18 weight ratio during processing could exceed the 0.1-0.9 range given above for concrete;
19 special processing techniques which involve the addition of water to pulp during breaking
20 up of the dried pulp may yield water-cement ratios of about 100 during processing; the
21 excess water would be removed using vacuum, pressure, heat, or combinations thereof in
22 order to reduce the water-cement ratio of the end product to about 0.1-0.9 by weight.

1 Cellulose fiber reinforced mortar and concrete mixtures can be mixed, transported,
2 placed, pumped, sprayed, slipformed, extruded, consolidated, finished and cured into end
3 products using all techniques applicable to mortar and concrete. The fibers could also be
4 added at any step during the mixing process. Alternatively, some or all the mix ingredients
5 could be added to the pulp prior to or during the breaking down of the dried pulp into
6 individual fibers, with the remaining mix ingredients, if any, added later during the mixing
7 process.

8 The presence of cellulose fibers in the mix increases the cohesiveness and
9 segregation resistance of the fresh mix and thus benefits some steps in the processing of
10 mortar and concrete; such steps include pumping, spraying, extrusion, finishing and the
11 like. As understood from the following Examples, the reinforcing action of cellulose fibers
12 in mortar and concrete enhances their toughness, strength, impact resistance, cracking
13 resistance, fatigue life, and durability.

14 *Example 1*

15 Pulp sheets dried by a conventional process and a process according to the
16 invention, respectively, were broken up into individual fibers using a hammer mill. The
17 same wet pulp was used to produce these pulp sheets; this wet pulp was obtained by the
18 kraft chemical pulping of southern pine and was also bleached. The first sheet was dried
19 by the common method applied to paper pulp where pressing of the wet pulp is heavily
20 relied on for the removal of water, yielding an average density of 0.86 g/cm^3 . The second
21 sheet according to the invention was dried with less reliance on pressing and more on
22 heating in order to reduce the density of the dried pulp sheet to 0.64 g/cm^3 . Separation of
23 individual fibers from the two dried pulp sheets in the same hammer mill yielded the

1 following results. The conventionally dried pulp which had strong hydrogen bonding
2 between fibers produced 4% by weight of multiple fiber agglomerates, 19% by weight of
3 fines passing #200 (74 micron opening) sieve, and an average fiber length of 0.92 mm.
4 The pulp dried according to the invention with less reliance on pressing which had reduced
5 fiber-to-fiber hydrogen bonding produced 0.1% by weight of multiple fiber agglomerates,
6 5.5% by weight of fines passing #200 (74 micron opening) sieve, and an average fiber
7 length of 1.3 mm. The drying process of the invention which reduced fiber-to-fiber
8 hydrogen bonding was thus successful in enhancing the effectiveness of the hammer mill in
9 separating the pulp sheets into individual fibers, and also in reducing the breaking of fibers
10 in the hammer mill.

11 The individual fibers separated from the two pulp sheets as above were added to
12 two similar fresh concrete mixtures at a dosage of 0.9 kg/m^3 which corresponds to a fiber
13 volume fraction of 0.06%. The concrete mix comprised Type I Portland cement, water,
14 crushed limestone of 19 mm maximum particle size as coarse aggregate and natural sand
15 of 5 mm maximum particle size as fine aggregate. The water-cement, fine aggregate-
16 cement and coarse aggregate-cement weight ratios were 0.564, 2.17 and 3.43,
17 respectively. The fibers were added to the fresh mix after all other ingredients were mixed
18 in a rotary drum mixer. Mixing was continued for about 3 minutes after the addition of
19 fibers in order to achieve a uniform dispersion of fibers. The fresh mix was then placed in
20 molds and vibrated into prismatic specimens of 100 mm square cross sections and a length
21 of 356 mm. These specimens were moist cured for 48 hours and then tested in flexure by
22 four-point loading over a span of 300 mm. The flexural strength obtained with fibers
23 separated from conventionally dried paper pulp with strong hydrogen bonding was 4.9

1 MPa while that with fibers separated according to the invention with less fiber-to-fiber
2 bonding was 6.2 MPa. This confirms that cellulose fibers from the same source offer
3 higher levels of reinforcement efficiency when separated from a dried pulp of lower
4 density with less extensive fiber-to-fiber hydrogen bonding. Analysis of the fractured
5 surfaces of the flexural specimens yielded about 10% lower variation in fiber count per
6 unit area for the invention example versus the comparative example; this indicates that
7 pulp fibers dried and separated according to the invention can be dispersed more uniformly
8 in concrete.

9 *Example 2*

10 The cellulose fiber reinforced concrete mixture according to the invention as in
11 Example 1 above as well as a corresponding fresh mix without the addition of fibers, were
12 molded and consolidated into specimens for the performance of compression (ASTM C
13 39), drop-ball impact (ACI Committee 544) and fracture bend (RILEM TC89-FMT) tests.
14 The compression specimens were 100 mm in diameter and 200 mm high. The impact test
15 specimens were 150 mm in diameter and 64 mm mm high. The fracture test specimens
16 were 100x100x457 mm prisms. Three compression, three impact, and three fracture test
17 specimens were prepared from each mix. The specimens were kept inside their molds
18 under a wet burlap for 24 hours, and were then demolded and subjected to 14 days of
19 moist curing followed by 14 days of air drying in laboratory prior to testing. The plain and
20 cellulose fiber reinforced concretes produced average compressive strengths of 30 and 40
21 MPa, respectively, ultimate impact strengths of 19 and 99 drops, respectively, and fracture
22 strengths of 3.1 and 5.3 MPa, respectively. These results confirm the effectiveness of the

1 cellulose fibers derived according to the invention in enhancing the impact resistance and
2 strength characteristics of concrete.

3 *Example 3*

4 The cellulose fiber derived according to the invention in Example 1 above was
5 added to a mortar mixture at 1% volume fraction. The mortar mix comprised Type I
6 Portland cement, silica fume, silica sand of 1.2 mm maximum particle size, water, and
7 superplasticizer. The silica sand-to-cement weight ratio was 1.075, silica fume-to-cement
8 weight ratio was 0.08, and water-to-cement weight ratio was 0.37. The dosage of
9 superplasticizer was 5.1 l/m³. The mortar mix was first prepared in a conventional mortar
10 mixer, and fibers were then added and dispersed in the mix through continuation of mixing
11 for about 3 minutes. The fresh mortar mix was molded and vibrated into twelve prismatic
12 specimens which were 25 mm thick and 50 mm wide. Comparative specimens were also
13 made from plain mortar of the same components without the addition of cellulose fibers.
14 All the specimens were retained in their molds under wet burlap for 24 hours, and were
15 subsequently demolded, moist-cured for 14 days, and air-dried for another 14 days. Three
16 of the specimens from each mix were then subjected to four-point flexure testing on a span
17 of 150 mm. The remaining specimens were divided to groups of three from each mix and
18 each group subjected to one of the following accelerated aging conditions: (1) 25 cycles of
19 wetting and drying, with each cycle comprising 3 hours of water spray at 23 degrees C
20 and 3 hours of drying at 60 degrees C; and (2) 14 days of immersion in warm water at 60
21 degrees C. All the specimens were subsequently subjected to four-point flexure testing on
22 a span of 150 mm. The unaged and aged flexural strength test results are described below.

1 The plain and cellulose fiber reinforced mortars reached unaged flexural strengths
2 at 28 days of 4 MPa and 7.7 MPa, respectively. This confirms the effectiveness of
3 cellulose fibers in enhancing the flexural strength of mortar. After both accelerated aging
4 processes, the plain and fiber reinforced mortars retained more than 95% of their flexural
5 strength. Hence, cellulose fibers retained their high flexural strength even after aging.

1 **Claims**

2 We claim:

- 3 1. A process for making a cellulose fiber reinforced cement-based material using
4 cellulose fibers derived through a wet process using at least one of mechanical,
5 thermal and chemical pulping methods, said process comprising the steps of:
- 6 a. drying wet cellulose pulp to a density of about 0.2-0.8 g/cm³ and moisture
7 content of about 0.1%-10% by weight;
- 8 b. separating the dried pulp into individual fibers through breaking fiber-to-
9 fiber bonds using mechanical action; and
- 10 c. adding the separated individual fibers at about 0.01%-40% fiber volume
11 fraction to a cement-based material comprising cement, aggregates, water,
12 with fibers and other ingredients added in any sequence, at an aggregate-
13 to-cement weight ratio of about 0.1-60 and water-to-cement weight ratio
14 of about 0.1-100, where the cement is any hydraulic or hydratable cement,
15 said aggregates are of at least one of mineral, synthetic, metallic and
16 organic sources with about 0.05-5 mm minimum particle size and about
17 0.1-100 mm maximum aggregate particle size, with the fiber and other
18 ingredients combined into a homogeneous blend.
- 19 2. The process of Claim 1, wherein the cement-based material is concrete, said
20 minimum aggregate particle size is about 0.05-3 mm, said maximum aggregate
21 particle size is about 9-100 mm, said aggregate-to-cement weight ratio is about 1-
22 10, and said water-to-cement weight ratio is about 0.1-0.9, said separation step
23 involves separating the individual fibers from the dried pulp without the addition of

- 1 water, and said separated fibers are added to said concrete at about 0.01%-5%
2 volume fraction.
- 3 3. The process of Claim 1, wherein the cement-based material is mortar, said
4 minimum aggregate particle size is about 0.05-1 mm, said maximum aggregate
5 particle size is about 0.1-6 mm, said aggregate-to-cement weight ratio is about
6 0.1-6, said water-to-cement weight ratio is about 0.1-0.9, said separation step
7 involves separating said individual fibers from the dried pulp without the addition
8 of water, and said individual fibers are added to the mortar at about 0.05%-20%
9 volume fraction.
- 10 4. The process of Claim 1 wherein, the said separation step involves separating the
11 individual fibers from the dried pulp using a mill without the addition of water
12 and the process further comprises the step of compacting the separated individual
13 fibers to a density of about 0.01-1 g/cm³ at about 0.1%-10% moisture content by
14 weight prior to said addition step.
- 15 5. The process of Claim 1, wherein the fiber separation step is accomplished with
16 some or all the ingredients of cement-based material added to the pulp.
- 17 6. The process of Claim 1, comprising a further step of forming the cement-based
18 material into a fiber reinforced cement-based structure, said forming step
19 including incorporation of about 0.01%-30% volume fraction of at least one of
20 continuous and discrete reinforcement of steel, synthetic, glass, mineral, natural
21 and fiber reinforced polymer and metal matrix composite types into the fiber
22 reinforced cement-based structure.

- 1 7. The process of Claim 1, wherein said cement-based material further comprises
2 admixtures of at least one of chemical, mineral, polymeric and air-entraining
3 types.
- 4 8. A hardened cellulose fiber reinforced cement structure comprising:
- 5 a. about 0.01%-40% by volume of cellulose fibers separated from pulp which
6 has been derived from at least one of wood, plants, and waste paper in a
7 wet process and dried to a density of about 0.2-0.8 g/cm³ and moisture
8 content of about 0.1%-10% by weight; and
- 9 b. a cement-based binder comprising cement, aggregates and water, at an
10 aggregate-to-cement weight ratio of about 0.1-60 and a water-to-cement
11 weight ratio of about 0.1-100, where cement is any hydraulic or hydratable
12 cement, said aggregate is of at least one of mineral, synthetic, metallic and
13 organic sources, with about 0.05-5 mm minimum aggregate particle size
14 and about 0.1-100 mm maximum aggregate particle size.
- 15 9. The cellulose fiber reinforced structure of Claim 8, wherein the cement-based
16 binder is concrete, said minimum aggregate particle size is about 0.05-3 mm, said
17 maximum aggregate particle size is about 9-100 mm, said aggregate-to-cement
18 weight ratio is about 1-10 and said water-to-cement weight ratio is about 0.1-0.9,
19 said cellulose fibers are separated from the dried pulp without the addition of
20 water, and added to the concrete at about 0.01%-5% volume fraction.
- 21 10. The cellulose fiber reinforced structure of Claim 8, wherein the cement-based
22 binder is mortar, said minimum aggregate particle size is about 0.05-1 mm, said
23 maximum aggregate particle size is about 0.1-6 mm, said aggregate-to-cement

1 weight ratio is about 0.1-6, said water-to-cement weight ratio is about 0.1-0.9, and
2 said cellulose fibers are separated from the dried pulp without the addition of
3 water, and added to the mortar at about 0.05%-20% volume fraction.

4 11. The cellulose fiber reinforced structure of Claim 8, wherein said structure further
5 comprises about 0.01%-30% volume fraction of at least one of continuous and
6 discrete reinforcement of at least one of steel, synthetic, glass, mineral, natural
7 and fiber reinforced polymer and metal matrix composite types.

8 12. The cellulose fiber reinforced structure of Claim 8, wherein said cement-based
9 binder further comprises admixtures of at least one of chemical, mineral,
10 polymeric and air-entraining types.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/18363

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : C04B 16/02, 16/12

US CL : 106/731, 805

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 106/731, 805

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONEElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 3,753,749 A [NUTT] 21 August 1973, col. 3, lines 45-66.	1-12
A	US 4,985,119 A [VINSON et al] 15 January 1991, see entire document.	1-12
A	US 5,102,596 A [LEMPFER et al] 07 April 1992, see entire document.	1-12

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

Special categories of cited documents:		*T		later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A	document defining the general state of the art which is not considered to be of particular relevance			
*E	earlier document published on or after the international filing date	*X	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	
*L	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Y	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	
*O	document referring to an oral disclosure, use, exhibition or other means			
*P	document published prior to the international filing date but later than the priority date claimed	*&	document member of the same patent family	

Date of the actual completion of the international search

16 DECEMBER 1996

Date of mailing of the international search report

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